Suppression of runaway electrons during disruption in HT-7

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Abstract:

One of the important problems of a large tokamak such as ITER is the disruption generated runaway electrons, which impinge the plasma facing components (PFC) and damage them. The experiments for mitigating and avoiding the current quench and runaway electrons during disruption have been carried out in HT-7 by LHW, massive gas injection and magnetic perturbation. The plasma current quenching time is typically 1~2ms for a major disruption in HT-7. When LHW was injected, the post-disruption current with a plateau can be sustained up to a soft termination of discharge. Current carried by LHCD driven electrons plays an important role in this operation scenario. Another way tried in HT-7 to suppress runaway electrons generated during major disruption is by magnetic oscillations. Radiation of runaway electrons nearly disappeared when strong magnetic oscillations exist. It seems to be the most effective way to suppress runaway electrons in HT-7.

1. Introduction

One of the important problems of a tokamak fusion reactor is the potential damage caused by disruption generated runaway electrons [1], and the plasma facing components (PFC) would be damaged if the localized and intense irradiation of runaway electrons occurs [2]. The high electric fields induced during the current quench phase of a tokamak disruption can generate a large number of runaway electrons with energies as high as several tens of MeV [3]. Intense runaway electrons with high energies of several tens of MeV generated at a major disruption would significantly reduce the lifetime of the first wall. Plasma disruptions in a large tokamak such as ITER are one of the most serious issues for the design of the plasma-facing components, blanket and vacuum vessel [4]. In consequence, there is a great concern about the damage that these energetic runaway electrons might cause if they impact on the first wall structures, which might be critical for larger devices such as the ITER tokamak [5], and it is necessary to mitigate and avoid the current quench artificially. In spite of the fact that considerable progress has been made in recent experiments in the design and testing of the mitigation techniques based on massive gas jets and pellet injection (see[6,7]) the problem of runaway suppression is still considered to be one of the primary task for a reliable tokamak operation[8].

On the other hand, the experiments for mitigating and avoiding the current quench by LHCD and ECRH have been carried out, such as JET [9], JT-60U [10], FTU [5], and TEXTOR [3]. In these experiments, runaway electrons can also be generated. The experiments for mitigating the current quench and suppressing runaway electrons simultaneously should be further carried out to enhance reliability of a tokamak safe operation.

The experiments for mitigating and avoiding the current quench have been carried out in HT-7 by LHW, massive gas injection and magnetic perturbation.

The observations and interpretations of the production and loss of the runaways during disruptions in HT-7 Tokamak are investigated in this paper. This paper is organized as follows. In section 2, the experimental set-up is introduced. Current quench in LHCD plasmas is presented in section 3. The mitigation of current quench with gas puffing in LHCD plasmas is presented in section 4. In section5, the current quench with strong magnetic oscillations in LHCD plasmas is presented. Finally, conclusions are presented in section 6.

2. Experimental set-up

HT-7 is a medium-sized tokamak with superconducting toroidal coils and water-cooled graphite limiters, constructed to achieve high-performance long pulse plasma discharges and to study relevant physics. The machine runs normally with plasma current I_p=100-250kA, the toroidal magnetic field B_T=1.5-2T, the central line-averaged plasma density n_e =(1-4)×$10^{19}$$m^{-3}$, major radius R=122cm, minor radius a=27cm, central electron temperature T_e=0.5-3.0keV, central ion temperature T_i =0.3-1.5keV, with circular cross section [11]. The plasma current, position and central line-averaged electron density were feedback controlled during discharges. A stainless-steel liner was installed in the vacuum chamber at the radius of 0.32m [12, 13]. A lower hybrid wave (LHW) power up to 1.2MW at 2.45GHz is available in the HT-7 tokamak. LHCD was used not only for sustaining the plasma discharges but also for current density profile control. The parallel refractive index of the launched waves can be adjusted to be in the range $1.25 < n_{//} < 3.45$ by means of the feedback control of the phase difference between adjacent waveguides [14] The corresponding energy of the superthermal resonant electrons was about 30-330keV.

The electron cyclotron emission, hard X-ray emission and fast electron bremsstrahlung (FEB) have been used as the main tool to investigate the behavior of runaway electrons. There are 15 channels of heterodyne radiometer for ECE measurement in the HT-7 tokamak. It measures the ECE in the frequency range 95–124 GHz. Formation of nonthermal electrons during LHCD phase results in substantial enhancement of the downshifted ECE. The acceleration of fast electrons into energetic runaways will reduce the ECE signal since its downshifted frequency is out of the measuring frequency range. Thus, the ECE signal provides considerable information about the evolution of fast electron population and low energy runaway population. The hard X-ray emission in the energy of 1.0-10.0MeV (typical energy ranges of runaway electrons) was detected by the NaI(TL) scintillator detectors arranged tangentially on the equatorial plane. It provides the considerable information on the HXR emission resulting from the thick target bremsstrahlung when runaway electrons are lost from the plasma and impinge on the vessel walls or plasma facing components. So we named this HXR emission detect system as runaway electron detect system which provides information on loss and the energy content of the runaway electrons. It can only measure those runaway electrons that are no longer confined. The information on runaway electrons inside of the plasmas was provided by ECE and FEB (including vertical hard X-ray detect system and tangential hard X-ray detect system). The fast electron bremsstrahlung in the energy of 30-250kev was measured by the vertical and tangential CdTe detectors array arranged inside of the vessel. It provides considerable information on the LHW power deposition profile and the spatial and velocity distribution of the electrons accelerated via Landau damping by LHW [14]. Based on the above diagnostics systems, Phenomena of runaway electrons during disruptions of discharges in the HT-7 tokamak were presented as the following.

3. Current quench in LHCD plasmas

A typical LHCD discharge is shown in figure 1. The plasma current was 120kA, the line-averaged density n_e=0.9×$10^{19}$$m^{-3}$; 200kW LHW power was launched into the plasma from 0.244s to 0.318s. After the ECE signal drop the plasma current I_p dropped and the loop voltage V_{loop} increase took place also at about t=0.3115s. Negative voltage spike and a small temporary increase of I_p were observed at the moment of disruption.

The plasma current quenching time is typically 1~2ms for a major disruption in HT-7 ohmic discharges. When LHW was injected, the post-disruption current with a plateau can be sustained up to a soft termination of discharge. As shown in Figure 1, the loop voltage was not significantly increased during application of LHW, which leads runaway electrons with limited energy indicated by low radiation level of high energy HX monitoring (RA in fig. 1). Current carried by LHCD driven electrons plays an important role in this operation scenario.

4. Mitigation of current quench with gas puffing in LHCD plasmas

Above experiments shows clearly that LHCD can be used to mitigate the current quench of a disruption, but runaway electrons were still generated. Furthermore, to suppress runaway electrons, massive deuterium is injected into plasma together with injection of LHW in HT-7. The plasma density is significantly increases with gas puff during the post-disruption current plateau. The amount of runaway electrons in this scenario is reduced compared to the discharge without gas injection after major disruption as shown in Figure 2. Furthermore, large increase of plasma density during disruption can lower the plasmas temperature and thus mitigate effects of thermal damage.

5. Current quench with strong magnetic oscillations in LHCD plasmas

LHCD can be used to mitigate the current quench of a disruption, but runaway electrons were still generated. Another way to suppress runaway electrons generated during major disruption is by magnetic oscillations. It has been tried in HT-7 shown in Figure 3. The plasma current was 120kA, the line-averaged density $n_e=0.9\times10^{19}m^{-3.}$ Radiation of runaway electrons nearly disappeared when strong magnetic oscillations exist, and the post-disruption current with a plateau can be sustained up to a soft termination of discharge. It seems to be the most effective way to suppress runaway electrons in HT-7.

6. Conclusions

The experiments for mitigating and avoiding the current quench have been carried out in HT-7 by LHW, massive gas injection and magnetic perturbation.

When LHW was injected, the post-disruption current with a plateau can be sustained up to a soft termination of discharge. Current carried by LHCD driven electrons plays an important role in this operation scenario.

To suppress runaway electrons, massive deuterium is injected into plasma together with injection of LHW in HT-7. The plasma density is significantly increases with gas puff during the post-disruption current plateau. The amount of runaway electrons in this scenario is reduced compared to the discharge without gas injection after major disruption.

Another way to suppress runaway electrons generated during major disruption is by magnetic oscillations. Radiation of runaway electrons nearly disappeared when strong magnetic oscillations exist. It seems to be the most effective way to suppress runaway electrons in HT-7.

The underlying physical mechanisms from these experiments is being analyzed and discussed in detail. These techniques for suppressing runaway electrons during major disruptions will be further verified in EAST, which is equipped with more diagnostics and has more capability for these investigations.

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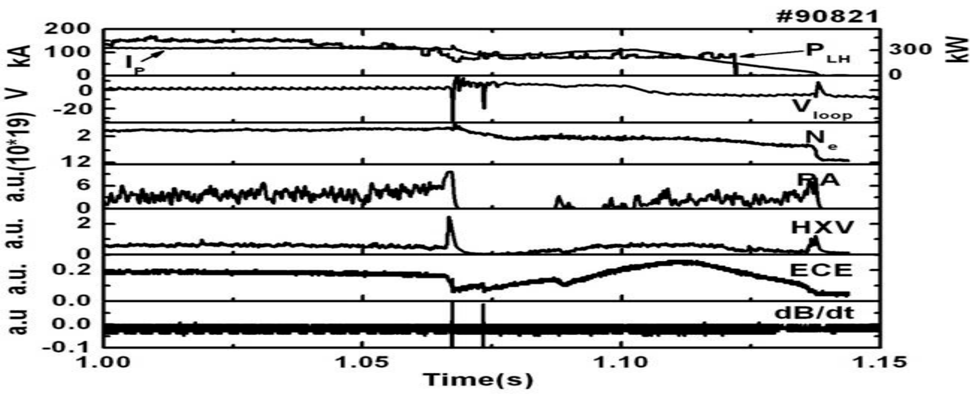

Figure 1. LHW injected into plasma during major disruption

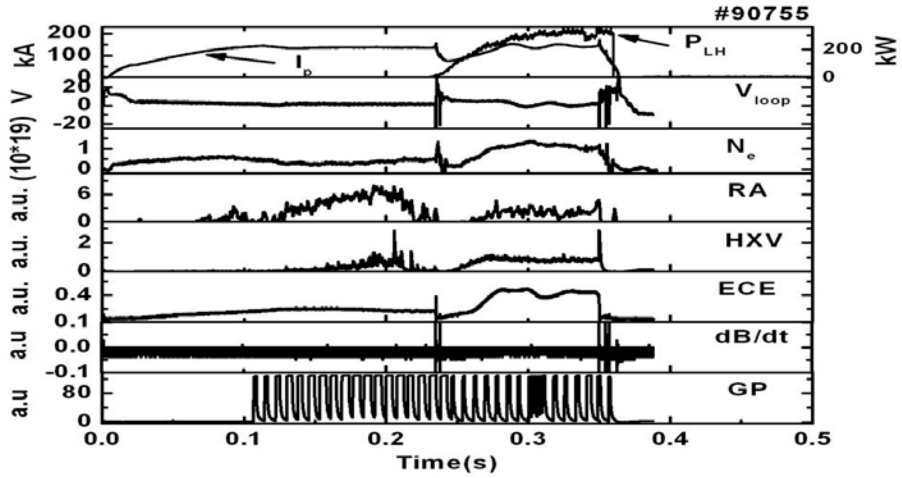

Figure 2. Gas puffing together with LHW during major disruption

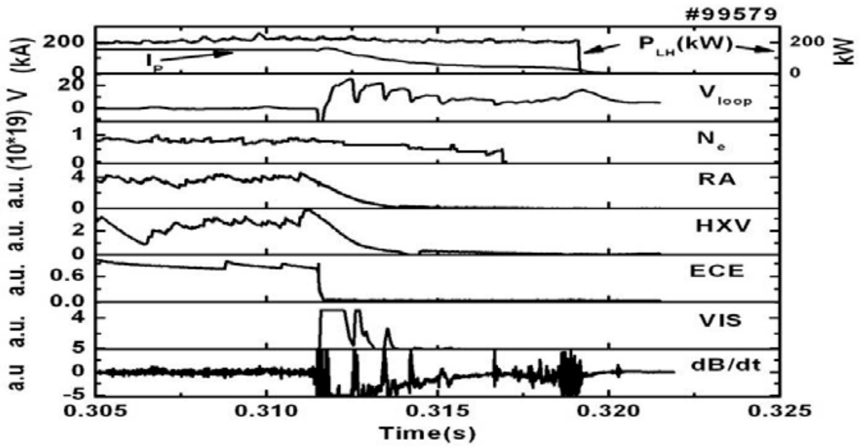

Figure 3. Strong magnetic oscillations kill runaway electrons